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# RESEARCH MEMORANDUM

## PERFORMANCE COMPARISONS OF NAVY JET MIX AND MIL-F-5624A (JP-3) FUELS IN TUBULAR AND ANNULAR COMBUSTORS

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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## SUMMARY

An investigation was conducted to compare the performances of Navy Jet Mix and MIL-F-5624A (JP-3) fuels in single combustors from current turbojet engines. The Navy Jet Mix fuel used was composed of three parts MIL-F-7914, grade JP-5 fuel and one part unleaded MIL-F-5572 fuel. Combustion efficiencies and altitude operational limits were determined with both fuels in the J33, J35, J47, and NACA experimental annular combustors in a range of altitude from 20,000 to 60,000 feet and engine rotor speed from 40- to 100-percent normal rated at a flight Mach number of 0.6. Carbon-forming tendencies of both fuels were determined in the J33 combustor.

The results indicate that the unleaded Jet Mix fuel could be utilized satisfactorily over the normal operating range in a number of representative current turbojet engines. Small (3 to 5 percent) positive or negative variations in combustion efficiency occurred between the two fuels but this variation depended on the particular engine operating condition. The Jet Mix fuel gave lower altitude limits than JP-3 fuel throughout the altitude-speed range investigated in the J33 combustor; however, with the other tubular combustors a difference in limits was obtained only in the low rotor-speed range. The variation in fuel type did not affect the altitude operational limits of the NACA experimental annular combustor. Excessive carbon deposition is not predicted for unleaded Jet Mix fuel although this property may be marginal. The aromatic content of this particular Jet Mix fuel was 13.4 percent; Jet Mix fuels containing higher percentages of aromatic constituents may give more carbon deposition. Also, the Jet Mix fuel tested did not contain the tetraethyl lead that would normally be present. The effects of the lead additive were not determined.

## INTRODUCTION

Carrier-based jet aircraft operate on high-volatility, low-flash-point fuel which must, for safety reasons, be stored in protected, centrally located bunkers aboard the carriers. The capacity of these bunkers is much less than the capacity of the perimeter bunkers containing the necessary fuel-oil supply. The jet-fuel capacity could be increased and the frequency of refueling decreased by utilizing some of these perimeter bunkers for jet-fuel storage. Safety requirements permit only high-flash-point (above 140° F) fuel to be stored in these unprotected bunkers and such fuel would not perform satisfactorily or meet freezing-point requirements in present turbojet aircraft. If a special kerosene type fuel were obtained which would meet the high-flash-point safety requirements, this fuel could then be stored in perimeter bunkers and blended with carrier reciprocating-engine aircraft gasoline (MIL-F-5572, grade 115/145) as required. A blend of 75-percent high-flash-point kerosene fuel (MIL-F-7914, grade JP-5) and 25-percent aviation gasoline met the freezing-point requirements and was designated Jet Mix fuel. The utilization of this fuel is contingent upon the satisfactory operation of jet engines on a blend of this type. 2428

Investigations comparing the performance of Jet Mix fuel and other fuels in current turbojet engines and their combustors were conducted at the NACA Lewis laboratory. Results of studies in a full-scale J34 turbojet engine comparing Jet Mix and unleaded clear gasoline fuels are reported in reference 1. This report presents data obtained with Jet Mix and MIL-F-5624A (JP-3) fuels in several single-combustor test units, and evaluates combustion efficiency, combustion stability, and carbon deposition. The Jet Mix fuel used in this investigation was blended by volume from one part unleaded MIL-F-5572 fuel and three parts MIL-F-7914, grade JP-5 fuel. The blend did not contain the tetraethyl lead that would be introduced with leaded MIL-F-5572, grade 115/145 fuel used aboard carriers.

Combustion efficiencies and altitude operational limits of both fuels were determined in J33, J35, J47, and NACA annular combustors. The tubular combustors were standard production units all currently operated on MIL-F-5624A (JP-3) fuel; the NACA annular combustor is an experimental unit developed to operate on MIL-F-5624A (JP-3) fuel. The performance variables were determined in a range of altitude from 20,000 to 60,000 feet, engine rotor speed from 40- to 100-percent normal rated, and a flight Mach number of 0.6. Carbon-forming tendencies of both fuels were determined in the J33 combustor only and the results are presented and discussed in relation to the NACA carbon-deposition correlation used in reference 2.

## APPARATUS AND PROCEDURE

The combustors used in this investigation were installed in the laboratory air-supply and exhaust ducting with valves located upstream and downstream to control air flow rates and pressures. Electric and gasoline-fired preheaters were used to control the combustor inlet-air temperatures. The detailed instrumentation and equipment features of the combustors used have been presented in previous NACA reports: the J33-A-23, the J35-C-3, the J47, and the NACA annular combustor, except for minor changes in air admission holes in the liner, in references 3, 4, 5, and 6, respectively.



Estimated combustor inlet-air conditions and combustor outlet-gas temperatures that were used to simulate engine operation at various altitudes and engine rotor speeds can be found for the J33, the J35, the J47, and the NACA annular combustors, in references 7, 4, 5, and 6, respectively.



The combustion efficiency values reported herein were computed as the ratio of the measured enthalpy rise of the fuel-air mixture across the combustor to the heating value of the fuel. A correction was made for the difference between the enthalpy of the carbon dioxide and water vapor in the burned mixture and the enthalpy of the oxygen removed from the air by the formation of the carbon dioxide and water vapor. The thermocouple indications were taken as true values of total temperature and no corrections were made for radiation or stagnation effects.

The data presented herein should not be used to compare combustor type and design because the values of combustion efficiency reported were, in some cases, obtained from a limited number of exhaust-gas temperature probes. However, the differences in performance obtained between the two fuels are considered sufficiently accurate as any temperature measuring errors would be present in both sets of data obtained with each combustor.

## FUELS

The analyses of the fuels used in this investigation are shown in table I. The MIL-F-5624A (JP-3) fuel (NACA fuel 51-186) was a representative batch as received from the supplier and met the JP-3 fuel specification with the exception of the freezing point, which was 14° F too high. The Jet Mix fuel (NACA fuel 51-201) was blended by volume at the Lewis laboratory from one part unleaded MIL-F-5572 fuel (NACA fuel 49-167) and three parts MIL-F-7914, grade JP-5 fuel (NACA fuel 51-170). The unleaded MIL-F-5572 fuel was the base stock used in the preparation of grade 115/145, MIL-F-5572 fuel.

The unleaded Jet Mix fuel falls within MIL-F-5624A (JP-4) fuel specifications except that the freezing point is 16° F too high; therefore, the comparisons between JP-3 and Jet Mix fuel performance are applicable to comparisons between JP-3 and JP-4 fuel performance.

## RESULTS AND DISCUSSION

### Combustion Efficiency and Altitude Operational Limits 2428

The data obtained with several combustors and Jet Mix and JP-3 fuels are summarized in table II. The variation of combustion efficiency with simulated engine rotor speed for the two fuels is shown in figure 1 for each combustor investigated over an altitude range from 20,000 to 60,000 feet. Cross plots showing the effect of altitude on the combustion efficiencies of the two fuels at two constant simulated rotor-speed values are presented in figure 2. A comparison of engine altitude operational limits obtained with both fuels for all the combustors is presented in figure 3.

<u>J33 combustor</u>. - The combustion efficiency values obtained in this combustor with Jet Mix fuel are nearly as high as those obtained with JP-3 fuel throughout the altitude and rotor-speed range investigated, the maximum difference being approximately 3 percent (fig. 1(a)). An exception is the high simulated rotor speed and 60,000-foot altitude condition where the combustion efficiency of JP-3 fuel decreases very rapidly to a value about 10 percent lower than that of the Jet Mix fuel. The altitude operational limits with Jet Mix fuel are 7500 to 8000 feet lower than the limits with JP-3 fuel, as shown in figure 3(a).

<u>J35 combustor</u>. - The combustion efficiency values obtained with Jet Mix fuel in this combustor are better than those obtained with JP-3 fuel at 90-percent simulated rated rotor speed; however, the order is reversed at the low simulated rotor-speed condition. The maximum difference in combustion efficiency at either speed was about 4 percent (fig. 2(b)). The altitude operational limit curves followed a similar pattern, with JP-3 fuel providing limits 12,000 feet higher than Jet Mix fuel at 40-percent simulated rotor speed, as shown in figure 3(b). As simulated rotor speed increased, the difference decreased; at 65-percent normal rated rotor speed, the altitude operational limits of the two fuels are identical.

<u>J47 combustor</u>. - The combustion efficiency data obtained with this combustor indicate the same trends observed in the J35 combustor; that is, at the low simulated rotor-speed condition (fig. 2(c)), the JP-3 fuel provides higher efficiency values over most of the altitude range investigated, whereas at the high simulated rotor-speed condition the order is reversed. The maximum difference in combustion efficiency was

greater with this combustor, being approximately 8 percent at the low simulated rotor-speed condition. The altitude limit curve obtained with each fuel is identical at each end of the range of rotor speeds investigated (fig. 3(c)), but elsewhere the limits observed with Jet Mix fuel were as much as 7000 feet lower.



Annular combustor. - The Jet Mix fuel gave higher efficiencies in the annular combustor at altitudes above 30,000 feet and the low simulated rotor-speed condition, with a maximum difference of 6 percent at 40,000 feet, as shown in figure 2(d). At the high simulated rotor-speed condition, the JP-3 fuel gave higher combustion efficiencies over the altitude range investigated, varying from 1 percent at 30,000 feet to 9 percent at 50,000 feet. No differences in altitude operational limits of the two fuels were observed in this combustor.

The three tubular combustors used in this investigation had, in general, higher altitude operational limits with JP-3 fuel than with Jet Mix fuel. The difference in combustion efficiency values obtained with each fuel depended on the specific altitude and rotor-speed condition simulated; generally, the JP-3 fuel provided efficiencies 3 to 5 percent higher than Jet Mix fuel at the lowest simulated rotor speeds and altitudes investigated, whereas the Jet Mix fuel provided efficiencies 2 to 3 percent higher than JP-3 fuel at the higher simulated rotor speeds and altitudes investigated. The trends in combustion efficiency data for the NACA annular combustor are opposite to those obtained with the tubular combustors and no difference in altitude limits was observed with the two fuels in the annular combustor.

## Carbon-Deposition Characteristics

The amounts of carbon formed by the two fuels in 4 hours of operation of the J33 combustor are plotted in figure 4 on a previously developed correlation curve given in reference 3. The unleaded Jet Mix fuel formed twice as much carbon (7 g) as did the particular JP-3 fuel used in this investigation. Single-combustor and full-scale engine carbon-deposition values are analyzed and plotted on this correlation in reference 2, showing that a fuel having an NACA K factor of 310 or less will not give carbon-deposition problems in current turbojet engines that have been designed for use with JP-3 type fuels. Figure 4 shows that Jet Mix fuel has a K factor of approximately 305 and therefore will operate satisfactorily without forming excessive carbon deposits. This fuel quality estimate does indicate, however, that Jet Mix fuel is marginal with respect to carbon deposition and that other Jet Mix fuels with a larger percentage of aromatic constituents can be expected to yield more carbon.

The tetraethyl lead additive that would be present when the fuel is blended from leaded MIL-F-5572 fuel aboard carriers could result in increased deposits. An investigation of carbon deposition in a J33 single combustor using fuels containing metallic organic additives, including tetraethyl lead, is described in reference 8. The results indicated that the concentration of tetraethyl lead that would be present in Jet Mix fuels used in carrier-based aircraft would probably decrease carbon formation but the added lead oxide deposition would probably increase the total weight of deposits.

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## CONCLUDING REMARKS

The performance investigation with both tubular and annular type combustors indicates that Jet Mix fuel can be used satisfactorily over the normal operating range in a number of representative current turbojet engines. A small (3 to 5 percent) gain or loss in combustion efficiency from that provided by the JP-3 fuel used in this investigation may result but the variation in performance may depend on the particular altitude and rotor speed condition at which the engine is operated if the Jet Mix fuel is used. In the J33 combustor, the altitude limits were lowered approximately 8000 feet with Jet Mix fuel throughout the simulated rotor speed and altitude range investigated. For the other tubular combustors, the Jet Mix fuel gave lower altitude limits than the JP-3 fuel only in the low simulated rotor-speed range. No difference in altitude-operational limits between fuels was found with the experimental NACA annular combustor. No excessive carbon deposits were encountered with unleaded Jet Mix fuel, although this fuel may be marginal in this respect.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, April 21, 1954

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TABLE I - FUEL ANALYSES

| Fuel properties | MIL-F-5624A (JP-3) (NACA fuel 51-186) | Navy Jet Mix (NACA fuel 51-201) | MIL-F-7914, grade JP-5 (NACA fuel 51-170) | Unleaded MIL-F-5572 (NACA fuel 49-167) |
|---|---|---|---|---|
| A.S.T.M. distillation D86-46, (°F) | | | | |
| Initial boiling point | 118 | 142 | 357 | 120 |
| Percentage evaporated | | | | |
| 5 | 158 | 192 | 371 | 136 |
| 10 | 177 | 230 | 375 | 161 |
| 20 | 205 | 289 | 385 | 182 |
| 30 | 234 | 338 | 393 | 196 |
| 40 | 263 | 371 | 402 | 205 |
| 50 | 294 | 394 | 411 | 210 |
| 60 | 328 | 407 | 421 | 217 |
| 70 | 359 | 420 | 433 | 221 |
| 80 | 397 | 436 | 448 | 227 |
| 90 | 433 | 457 | 464 | 239 |
| Final boiling point | 492 | 499 | 502 | 309 |
| Residue (percent) | 1.3 | 1.1 | 0.7 | 1.0 |
| Loss (percent) | 1.1 | 1.0 | .2 | 2.0 |
| Freezing point (°F) | -62 | -60 | ----- | ----- |
| Aromatics Silica gel (percent by volume) | 9.0 | 13.4 | ----- | ----- |
| Olefins Silica gel (percent by weight) | .5 | .5 | ----- | ----- |
| Gravity | | | | |
| °API | 55.8 | 48.7 | 43.7 | 66.3 |
| Specific | .756 | .785 | .808 | .715 |
| Reid vapor pressure (lb/sq in.) | 6.5 | 2.0 | .2 | 5.0 |
| Hydrogen-carbon ratio | .171 | .164 | ------- | ------ |
| Heat of combustion (Btu/lb) | 18,740 | 18,670 | ------- | ------ |
| Gum, (mg/100 ml) | | | | |
| Air jet residue | 1 | 2 | ------- | ------ |
| Accelerated | 5 | 4 | ------- | ------ |
| Aniline point (°F) | 137.1 | 142.2 | 145.8 | ------ |
| Bromine number | .7 | .5 | ------- | ------ |
| Flash point (°F) | --------- | ---------- | 142 | ------ |

TABLE II - PERFORMANCE DATA FROM SEVERAL COMBUSTORS OPERATING WITH MIL-F-5624A (JP-3) AND JET MIX FUELS AT MACH NUMBER 0.60

(a) J33 combustor

| Simulated altitude (ft) | Percent rated engine speed | Combustor inlet total pressure (in. Hg) | Combustor inlet temperature (°R) | Air flow (lb/sec) | Combustor reference velocity (ft/sec) | Fuel flow (lb/hr) | Fuel-air ratio | Mean combustor outlet temperature (°R) | Mean temperature rise through combustor (°F) | Combustion efficiency | Total-pressure drop through combustor (in. Hg) | Fuel nozzle differential pressure (in. Hg) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MIL-F-5624A (JP-3) fuel | | | | | | | | | | | | |
| 20,000 | 60 | 33.2 | 605 | 2.13 | 109 | 50.7 | 0.00661 | 995 | 390 | 0.781 | 2.9 | 6 |
| | 70 | 41.3 | 654 | 2.68 | 119 | 64.4 | .00667 | 1090 | 436 | .873 | 3.8 | 12 |
| | 80 | 51.5 | 709 | 3.13 | 121 | 83.6 | .00742 | 1245 | 536 | .979 | 4.6 | 57 |
| | 90 | 65.5 | 732 | 3.43 | 108 | 129.4 | .0105 | 1515 | 783 | 1.03 | 4.9 | 76 |
| 30,000 | 60 | 22.6 | 570 | 1.52 | 108 | 40.5 | .00740 | 930 | 360 | .642 | 2.2 | -- |
| | 70 | 28.3 | 616 | 1.90 | 116 | 49.7 | .00727 | 1045 | 425 | .785 | 2.9 | 7 |
| | 80 | 35.9 | 670 | 2.21 | 116 | 64.5 | .00811 | 1225 | 555 | .925 | 3.3 | 13 |
| | 80 | 35.9 | 669 | 2.20 | 115 | 65.5 | .00827 | 1230 | 561 | .918 | 3.2 | 13 |
| | 90 | 45.2 | 724 | 2.44 | 110 | 95.4 | .0108 | 1510 | 786 | 1.01 | 3.8 | 39 |
| | 100 | 55.3 | 778 | 2.80 | 103 | 139.8 | .0149 | 1845 | 1067 | 1.03 | 3.8 | 92 |
| 40,000 | 60 | 14.5 | 548 | 1.02 | 109 | 34.6 | .00946 | 908 | 357 | .498 | 1.5 | --- |
| | 70 | 18.5 | 596 | 1.24 | 112 | 37.6 | .00846 | 1010 | 414 | .652 | 1.2 | -- |
| | 80 | 23.5 | 647 | 1.44 | 112 | 47.3 | .00916 | 1210 | 563 | .831 | 2.2 | 8 |
| | 90 | 29.8 | 700 | 1.59 | 106 | 67.1 | .0118 | 1500 | 800 | .943 | 2.3 | 17 |
| | 100 | 36.3 | 753 | 1.71 | 99.9 | 97.4 | .0158 | 1820 | 1067 | .971 | 2.5 | 42 |
| 50,000 | 60 | 9.0 | 550 | .648 | 110 | ←Required temperature rise unattainable→ | | | | | | --- |
| | 60 | 9.0 | 550 | .642 | 110 | 32.0 | .0138 | 910 | 360 | .348 | 1.2 | --- |
| | 70 | 11.5 | 598 | .787 | 115 | 51.4 | .0111 | 1015 | 419 | .505 | 1.2 | --- |
| | 80 | 14.5 | 648 | .905 | 114 | 55.0 | .0107 | 1210 | 562 | .715 | 1.5 | --- |
| | 90 | 18.2 | 702 | .986 | 107 | 45.1 | .0127 | 1500 | 798 | .876 | 1.7 | --- |
| | 100 | 22.5 | 754 | 1.010 | 95.2 | 62.0 | .0171 | 1815 | 1061 | .895 | 1.5 | -- |
| 60,000 | 70 | 7.2 | 596 | .485 | 113 | 43.6 | .0250 | 1010 | 414 | .229 | .9 | -- |
| | 80 | 9.1 | 648 | .560 | 112 | 40.0 | .0199 | 1215 | 567 | .396 | .9 | -- |
| | 90 | 11.4 | 699 | .609 | 105 | 39.1 | .0178 | 1500 | 801 | .636 | 1.0 | -- |
| | 100 | 14.0 | 753 | .654 | 99.0 | 44.1 | .0187 | 1820 | 1067 | .828 | 1.0 | -- |
| Jet Mix fuel | | | | | | | | | | | | |
| 20,000 | 60 | 33.1 | 606 | 2.13 | 109 | 52.0 | 0.00680 | 998 | 389 | 0.781 | 2.9 | 7 |
| | 70 | 41.3 | 655 | 2.67 | 119 | 63.0 | .00655 | 1090 | 435 | .690 | 3.7 | 12 |
| | 80 | 51.6 | 710 | 3.13 | 121 | 85.5 | .00759 | 1246 | 536 | .959 | 5.0 | 57 |
| | 90 | 65.0 | 727 | 3.52 | 111 | 138.1 | .0109 | 1510 | 783 | 1.00 | 5.0 | 76 |
| 30,000 | 60 | 22.6 | 569 | 1.54 | 109 | 42.6 | .00768 | 935 | 366 | .632 | 2.2 | 6 |
| | 70 | 28.3 | 616 | 1.89 | 116 | 50.8 | .00747 | 1040 | 424 | .758 | 2.9 | 7 |
| | 80 | 35.9 | 670 | 2.21 | 116 | 66.5 | .00836 | 1230 | 560 | .910 | 3.2 | 13 |
| | 80 | 35.8 | 670 | 2.20 | 115 | 66.0 | .00833 | 1225 | 555 | .905 | 3.3 | 13 |
| | 90 | 45.2 | 724 | 2.44 | 110 | 97.2 | .0111 | 1505 | 781 | .982 | 3.5 | 40 |
| | 100 | 55.6 | 778 | 3.81 | 103 | 144.2 | .0153 | 1845 | 1067 | 1.01 | 3.8 | 98 |
| 40,000 | 60 | 14.4 | 549 | 1.04 | 112 | 36.9 | .00986 | 906 | 356 | .479 | 1.6 | -- |
| | 60 | 14.4 | 547 | 1.02 | 109 | 36.7 | .0100 | 905 | 358 | .475 | 1.5 | -- |
| | 70 | 18.6 | 596 | 1.24 | 112 | 38.9 | .00870 | 1010 | 414 | .636 | 1.8 | -- |
| | 80 | 23.4 | 647 | 1.43 | 111 | 49.1 | .00953 | 1210 | 563 | .802 | 2.2 | 8 |
| | 90 | 29.6 | 701 | 1.58 | 105 | 67.9 | .0120 | 1500 | 799 | .930 | 2.3 | 16 |
| | 100 | 36.3 | 752 | 1.70 | 99.0 | 98.5 | .0161 | 1820 | 1068 | .958 | 2.5 | 40 |
| 50,000 | 60 | 9.0 | 549 | .846 | 110 | ---- | ←Required temperature rise unattainable→ | | | | | |
| | 70 | 11.5 | 596 | .793 | 116 | 34.1 | .0120 | 1010 | 414 | .464 | 1.3 | -- |
| | 80 | 14.5 | 648 | .900 | 113 | 36.4 | .0112 | 1210 | 562 | .665 | 1.5 | -- |
| | 90 | 18.2 | 702 | .980 | 106 | 47.0 | .0133 | 1500 | 798 | .841 | 1.6 | -- |
| | 100 | 22.5 | 753 | .985 | 92.8 | 65.0 | .0178 | 1820 | 1067 | .870 | 1.6 | 15 |
| 60,000 | 90 | 11.4 | 700 | .612 | 106 | 33.6 | .0153 | 1500 | 800 | .736 | 1.0 | -- |
| | 100 | 14.0 | 753 | .652 | 98.8 | 44.4 | .0189 | 1825 | 1072 | .825 | 1.0 | --- |

TABLE II - PERFORMANCE DATA FROM SEVERAL COMBUSTORS OPERATING WITH MIL-F-5624A (JP-3) AND JET MIX FUELS AT MACH NUMBER 0.60 - Continued

(b) J35 combustor

| Simulated altitude (ft) | Simulated engine speed (rpm) | Combustor inlet static pressure (in. Hg) | Combustor inlet temperature (°R) | Air flow (lb/sec) | Combustor reference velocity (ft/sec) | Fuel flow (lb/hr) | Fuel air ratio | Mean combustor outlet temperature (°R) | Mean temperature rise through combustor (°F) | Combustion efficiency | Total pressure drop through combustor (in. Hg) | Fuel nozzle differential pressure (in. Hg) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MIL-F-5624A (JP-3) fuel | | | | | | | | | | | | |
| 20,000 | 3000 | 23 | 530 | 1.4 | 50.6 | 18.5 | 0.00367 | 740 | 210 | 0.740 | -- | -- |
| | 4000 | 27 | 570 | 2.3 | 76.1 | 28.5 | .00344 | 810 | 240 | .907 | -- | -- |
| | 5000 | 35 | 610 | 3.2 | 87.4 | 52 | .00452 | 925 | 318 | .914 | -- | 51 |
| | 6000 | 47 | 675 | 4.3 | 96.8 | 100 | .00646 | 1140 | 465 | .965 | -- | 57 |
| 30,000 | 3000 | 15 | 490 | 1.0 | 51.2 | 19 | .00528 | 690 | 200 | .490 | -- | -- |
| | 4000 | 19 | 525 | 1.6 | 69.3 | 23.5 | .00408 | 760 | 255 | .748 | -- | -- |
| | 5000 | 24 | 575 | 2.3 | 86.4 | 38.5 | .00465 | 885 | 310 | .870 | -- | 33 |
| | 6000 | 33 | 635 | 3.0 | 90.5 | 77 | .00713 | 1130 | 495 | .928 | -- | 63 |
| | 7000 | 44 | 700 | 5.6 | 89.7 | 153 | .0118 | 1510 | 810 | .954 | -- | 77 |
| 40,000 | 3000 | 10 | 490 | 0.70 | 55.8 | 7.0 | .00278 | ← Lean limit blow-out → | | | | |
| | 4000 | 12 | 505 | 1.1 | 72.6 | 20 | .00505 | 740 | 235 | .602 | -- | -- |
| | 5000 | 15 | 555 | 1.5 | 87.0 | 28.5 | .00528 | 860 | 305 | .756 | -- | 18 |
| | 6000 | 21 | 615 | 2.0 | 91.8 | 55 | .00764 | 1120 | 505 | .882 | -- | 58 |
| | 7000 | 28 | 680 | 2.3 | 87.4 | 102 | .0123 | 1510 | 830 | .938 | -- | 76 |
| | 8000 | 34 | 740 | 2.6 | 88.6 | 164 | .0175 | 1900 | 1160 | .960 | -- | 87 |
| 50,000 | 4000 | 8 | 505 | 0.70 | 89.3 | 15.5 | .00615 | ← Lean limit blow-out → | | | | |
| | 5000 | 10 | 550 | 0.90 | 77.6 | 23 | .00710 | 860 | 310 | .573 | -- | -- |
| | 6000 | 14 | 615 | 1.2 | 82.6 | 42 | .00972 | 1120 | 505 | .697 | -- | 59 |
| | 7000 | 18 | 680 | 1.4 | 82.9 | 72 | .0143 | 1510 | 830 | .811 | -- | 78 |
| | 8000 | 21 | 740 | 1.6 | 88.3 | 113 | .0196 | 1900 | 1160 | .862 | -- | 85 |
| 60,000 | 5000 | 7 | 550 | 0.70 | 86.2 | 21 | .00633 | ← Lean limit blow-out → | | | | |
| | 6000 | 9 | 615 | 0.90 | 86.4 | 51 | .0157 | 1120 | 505 | .438 | -- | 61 |
| | 7000 | 12 | 680 | 1.0 | 88.8 | 64 | .0178 | 1510 | 830 | .657 | -- | 76 |
| | 8000 | 15 | 740 | 1.1 | 88.0 | 86 | .0217 | 1900 | 1160 | .784 | -- | 83 |
| Jet Mix fuel | | | | | | | | | | | | |
| 20,000 | 3000 | 23 | 550 | 1.4 | 50.6 | 20.0 | 0.00597 | 740 | 210 | 0.886 | -- | -- |
| | 4000 | 27 | 570 | 2.3 | 76.1 | 30.5 | .00368 | 810 | 240 | .850 | -- | 26 |
| | 5000 | 35 | 610 | 3.2 | 87.4 | 53 | .00460 | 925 | 315 | .902 | -- | 51 |
| | 6000 | 47 | 675 | 4.3 | 96.8 | 104 | .00872 | 1140 | 465 | .932 | -- | 64 |
| 30,000 | 3000 | 15 | 490 | 1.0 | 61.2 | 17.0 | .00472 | ← Lean limit blow-out → | | | | |
| | 4000 | 19 | 525 | 1.6 | 69.3 | 25.0 | .00434 | 760 | 235 | .706 | -- | -- |
| | 5000 | 24 | 578 | 2.3 | 86.4 | 40.0 | .00483 | 885 | 310 | .843 | -- | 40 |
| | 6000 | 35 | 635 | 3.0 | 90.5 | 82 | .00759 | 1130 | 495 | .877 | -- | 65 |
| | 7000 | 44 | 695 | 3.6 | 89.1 | 157 | .0121 | 1510 | 815 | .940 | -- | 77 |
| 40,000 | 4000 | 12 | 505 | 1.1 | 72.6 | 28.5 | .00720 | 740 | 235 | .426 | -- | -- |
| | 5000 | 15 | 580 | 1.5 | 87.8 | 29.5 | .00546 | 860 | 300 | .722 | -- | 24 |
| | 6000 | 21 | 615 | 2.0 | 91.8 | 60 | .00833 | 1120 | 505 | .814 | -- | 65 |
| | 7000 | 28 | 680 | 2.3 | 87.4 | 106 | .0128 | 1510 | 830 | .906 | -- | 78 |
| | 8000 | 34 | 740 | 2.6 | 88.6 | 172 | .0184 | 1900 | 1160 | .918 | -- | 89 |
| 50,000 | 4000 | 8 | 500 | 0.71 | 69.6 | 24.5 | .00958 | ← Lean limit blow-out → | | | | |
| | 5000 | 10 | 560 | 0.90 | 79.0 | 21.5 | .00664 | 860 | 300 | .596 | -- | -- |
| | 6000 | 14 | 615 | 1.2 | 82.6 | 47.0 | .0109 | 1120 | 505 | .626 | -- | 52 |
| | 7000 | 18 | 680 | 1.4 | 82.9 | 69 | .0137 | 1510 | 830 | .847 | -- | 74 |
| | 8000 | 21 | 740 | 1.6 | 88.3 | 110 | .0191 | 1900 | 1160 | .886 | -- | 85 |
| 60,000 | 5000 | 7 | 560 | 0.70 | 87.8 | 21.0 | .00833 | ← Lean limit blow-out → | | | | |
| | 6000 | 9 | 615 | 0.90 | 96.4 | 56 | .0173 | 1120 | 505 | .400 | -- | 69 |
| | 7000 | 12 | 680 | 1.0 | 88.8 | 64 | .0178 | 1510 | 830 | .660 | -- | 76 |
| | 8000 | 15 | 740 | 1.1 | 88.0 | 85 | .0215 | 1900 | 1160 | .792 | -- | 81 |

TABLE II - PERFORMANCE DATA FROM SEVERAL COMBUSTORS OPERATING WITH MIL-F-5624A (JP-3) AND JET MIX FUELS AT MACH NUMBER 0.60 - Continued

(c) J47 combustor

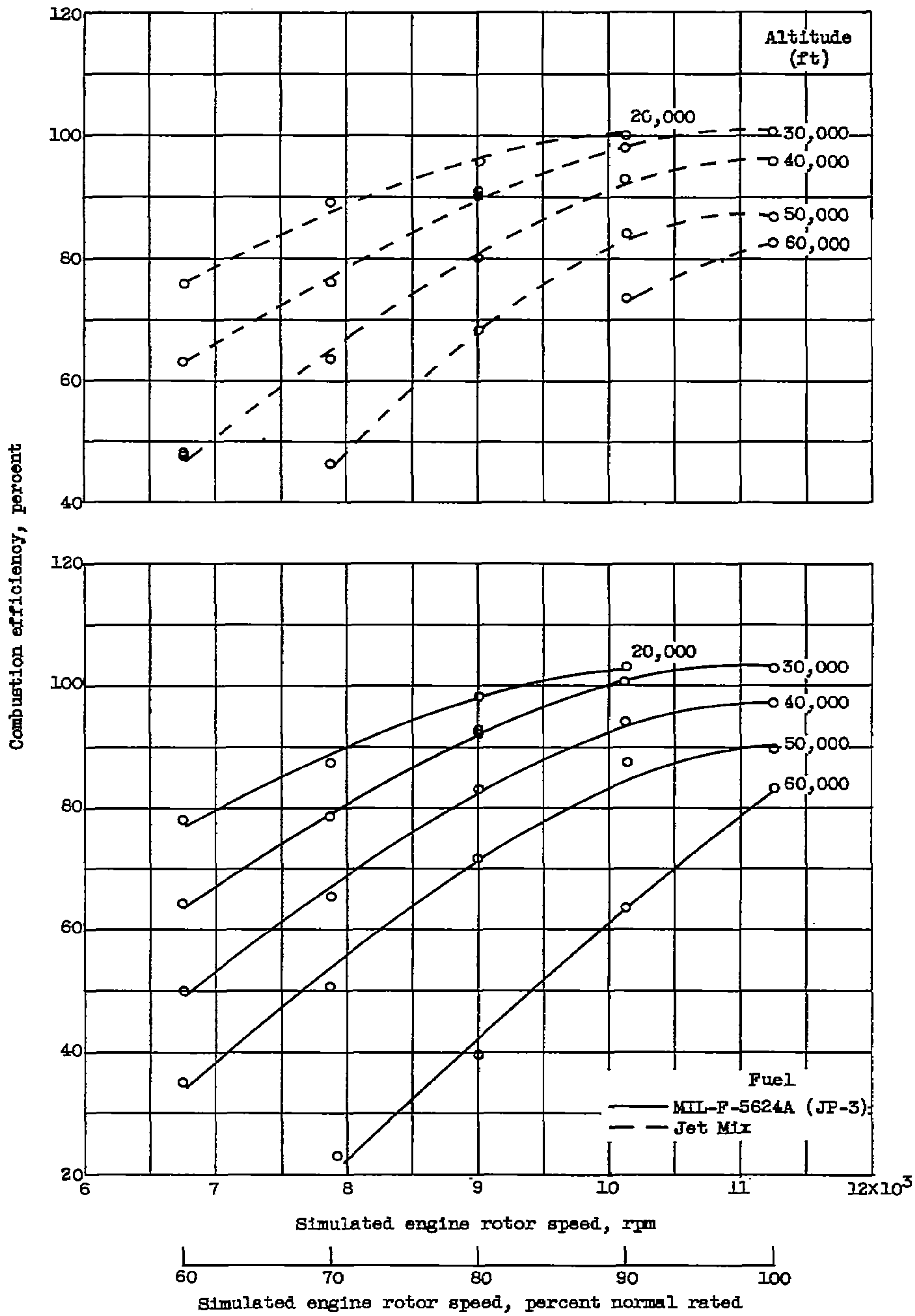
| Simulated altitude (ft) | Simulated engine speed (rpm) | Combustor inlet total pressure (in. Hg) | Combustor inlet temperature (°R) | Air flow (lb/sec) | Combustor reference velocity (ft/sec) | Fuel flow (lb/hr) | Fuel air ratio | Mean combustor outlet temperature (°R) | Mean temperature rise through combustor (°F) | Combustion efficiency | Total pressure drop through combustor (in. Hg) | Fuel nozzle differential pressure (in. Hg) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MIL-F-5624A (JP-3) fuel | | | | | | | | | | | | |
| 20,000 | 3000 | 20.7 | 528 | 2.21 | 88.0 | 22.9 | 0.00288 | 650 | 122 | .546 | -- | --- |
| | 4000 | 28.0 | 584 | 3.24 | 106 | 30.8 | .00264 | 745 | 161 | .790 | -- | 7 |
| | 5000 | 42.7 | 653 | 4.46 | 107 | 48.4 | .00301 | 865 | 212 | .921 | -- | 21 |
| 30,000 | 4000 | 19.3 | 550 | 2.27 | 102 | 25.7 | .00315 | 705 | 155 | .637 | -- | --- |
| | 5000 | 30.2 | 618 | 3.19 | 103 | 39.6 | .00345 | 840 | 222 | .841 | -- | 13 |
| | 6000 | 43.4 | 694 | 4.22 | 106 | 85.9 | .00565 | 1105 | 411 | .972 | -- | 78 |
| 40,000 | 4000 | 12.7 | 532 | 1.51 | 99.2 | 18.4 | .00338 | 690 | 158 | .604 | -- | --- |
| | 5000 | 19.6 | 598 | 2.09 | 100 | 30.0 | .00398 | 815 | 217 | .711 | -- | --- |
| | 6000 | 28.0 | 670 | 2.75 | 103 | 61.3 | .00619 | 1090 | 420 | .906 | -- | 39 |
| | 7000 | 35.5 | 754 | 3.07 | 102 | 127 | .0115 | 1550 | 796 | .971 | -- | 158 |
| | 7500 | 38.7 | 784 | 3.11 | 98.9 | 168 | .0151 | 1800 | 1016 | .970 | -- | 178 |
| 50,000 | 4000 | 7.8 | 530 | 0.981 | 105 | 15.5 | .00438 | Lean limit blow-out | | | | |
| | 5000 | 12.2 | 588 | 1.30 | 98.3 | 23.6 | .00502 | 825 | 237 | .617 | -- | --- |
| | 6000 | 17.7 | 674 | 1.72 | 103 | 42.8 | .00686 | 1085 | 411 | .802 | -- | 18 |
| | 7000 | 22.2 | 760 | 1.92 | 103 | 84.5 | .0125 | 1535 | 795 | .912 | -- | 82 |
| | 7900 | 25.3 | 828 | 1.81 | 98.2 | 130 | .0189 | 2010 | 1181 | .922 | -- | 161 |
| 60,000 | 4000 | 5.8 | 555 | 0.687 | 103 | 17.0 | .00687 | Lean limit blow-out | | | | |
| | 5000 | 8.8 | 595 | 0.938 | 99.6 | 23.5 | .00696 | 810 | 215 | .408 | -- | --- |
| | 6000 | 12.1 | 675 | 1.24 | 108 | 38.5 | .00861 | 1085 | 410 | .640 | -- | --- |
| | 7000 | 15.3 | 751 | 1.37 | 106 | 65.0 | .0128 | 1550 | 799 | .879 | -- | 45 |
| | 7900 | 17.6 | 828 | 1.38 | 102 | 98.5 | .0198 | 2010 | 1182 | .883 | -- | 118 |
| Jet Mix fuel | | | | | | | | | | | | |
| 20,000 | 3000 | 20.8 | 530 | 2.19 | 87.7 | 26.3 | 0.00333 | 655 | 125 | 0.487 | -- | --- |
| | 4000 | 28.0 | 583 | 3.24 | 108 | 33.2 | .00285 | 750 | 167 | .762 | -- | 7 |
| | 5000 | 42.7 | 653 | 4.50 | 108 | 49.5 | .00306 | 860 | 207 | .890 | -- | 20 |
| 30,000 | 4000 | 19.3 | 550 | 2.26 | 101 | 29.5 | .00362 | 705 | 158 | .557 | -- | --- |
| | 5000 | 30.2 | 618 | 3.18 | 102 | 39.5 | .00344 | 830 | 212 | .807 | -- | 13 |
| | 6000 | 43.4 | 691 | 4.24 | 106 | 88.6 | .00581 | 1110 | 419 | .969 | -- | 88 |
| 40,000 | 4000 | 12.7 | 550 | 1.50 | 102 | 28.0 | .00517 | Lean limit blow-out | | | | |
| | 5000 | 19.6 | 598 | 2.09 | 101 | 31.8 | .00423 | 810 | 212 | .657 | -- | --- |
| | 6000 | 28.0 | 672 | 2.75 | 104 | 62.4 | .00630 | 1090 | 418 | .890 | -- | 37 |
| | 7000 | 35.5 | 755 | 3.06 | 102 | 127 | .00115 | 1550 | 795 | .970 | -- | 150 |
| | 7500 | 38.7 | 793 | 3.07 | 99.0 | 166 | .0150 | 1805 | 1012 | .977 | -- | 171 |
| 50,000 | 4000 | 7.8 | 540 | 0.947 | 99.9 | 20.4 | .00599 | Lean limit blow-out | | | | |
| | 5000 | 12.0 | 602 | 1.30 | 103 | 21.5 | .00458 | 790 | 188 | .538 | -- | --- |
| | 6000 | 17.7 | 674 | 1.75 | 104 | 44.9 | .00720 | 1095 | 421 | .787 | -- | 17 |
| | 7000 | 22.2 | 757 | 1.92 | 103 | 82.0 | .0118 | 1545 | 788 | .933 | -- | 74 |
| | 7900 | 25.3 | 830 | 1.91 | 98.1 | 130 | .0189 | 2020 | 1190 | .933 | -- | 155 |
| 60,000 | 5000 | 8.8 | 597 | 0.094 | 100 | 19.2 | .00567 | 830 | 233 | .541 | -- | --- |
| | 6000 | 12.1 | 671 | 1.24 | 108 | 35.2 | .00789 | 1085 | 414 | .707 | -- | --- |
| | 7000 | 15.3 | 750 | 1.37 | 105 | 63.5 | .0129 | 1555 | 805 | .882 | -- | 40 |
| | 7900 | 17.6 | 827 | 1.38 | 102 | 98.2 | .0197 | 2010 | 1183 | .890 | -- | 105 |

TABLE II - PERFORMANCE DATA FROM SEVERAL COMBUSTORS OPERATING WITH MIL-F-5624A (JP-3) AND JET MIX FUELS AT MACH NUMBER 0.60 - Concluded

(d) NACA annular combustor

| Simulated altitude (ft) | Simulated engine speed (rpm) | Combustor inlet total pressure (in. Hg) | Combustor inlet temperature (°R) | Air flow (lb/sec) | Combustor reference velocity (ft/sec) | Fuel Flow (lb/hr) | Fuel air ratio | Mean combustor outlet temperature (°R) | Mean temperature rise through combustor (°F) | Combustion Efficiency | Total pressure drop through combustor (in. Hg) | Manifold differential pressure (in. Hg) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MIL-F-5624A (JP-3) fuel | | | | | | | | | | | | |
| 30,000 | 7,800 | 19.7 | 540 | 3.03 | 85.8 | 112 | 0.0103 | 1155 | 615 | 0.803 | --- | --- |
| | 8,700 | 23.5 | 560 | 3.67 | 90.5 | 132 | .0100 | 1195 | 635 | .855 | --- | --- |
| | 9,600 | 28.2 | 604 | 4.35 | 96.4 | 169 | .0108 | 1303 | 699 | .885 | --- | --- |
| 40,000 | 7,800 | 12.5 | 560 | 1.91 | 88.5 | 102 | .0148 | 1260 | 700 | .660 | --- | --- |
| | 8,700 | 15.9 | 540 | 2.31 | 81.0 | 119 | .0144 | 1223 | 683 | .659 | --- | --- |
| | 9,600 | 18.1 | 579 | 2.71 | 89.7 | 121 | .0124 | 1316 | 737 | .812 | --- | --- |
| | 10,400 | 21.3 | 612 | 3.05 | 90.6 | 157 | .0143 | 1485 | 873 | .856 | --- | --- |
| | 11,300 | 24.7 | 653 | 3.32 | 90.7 | 204 | .0171 | 1762 | 1109 | .930 | --- | --- |
| 50,000 | 10,400 | 12.8 | 602 | 1.65 | 80.3 | 167 | .0283 | 1720 | 1118 | .599 | --- | --- |
| | 11,300 | 15.1 | 663 | 1.83 | 83.0 | 167 | .0254 | 1997 | 1334 | .789 | --- | --- |
| 55,000 | 11,300 | 11.8 | 646 | 1.27 | 72.0 | 135 | .0296 | 2100 | 1454 | .755 | --- | --- |
| Jet Mix fuel | | | | | | | | | | | | |
| 30,000 | 7,800 | 19.7 | 544 | 3.04 | 86.9 | 113 | 0.0103 | 1156 | 612 | 0.800 | --- | --- |
| | 8,700 | 23.5 | 544 | 3.68 | 88.2 | 133 | .0100 | 1184 | 640 | .859 | --- | --- |
| | 9,600 | 28.2 | 600 | 4.41 | 96.2 | 168 | .0106 | 1289 | 689 | .883 | --- | --- |
| 40,000 | 6,100 | 8.30 | 480 | 1.21 | 72.4 | Required temperature rise unattainable | | | | | | |
| | 7,000 | 10.1 | 500 | 1.50 | 76.7 | Required temperature rise unattainable | | | | | | |
| | 7,800 | 12.5 | 544 | 1.91 | 86.0 | 89.0 | .0130 | 1211 | 667 | .709 | --- | --- |
| | 8,700 | 14.9 | 544 | 2.32 | 87.6 | 102 | .0122 | 1234 | 690 | .780 | --- | --- |
| | 9,600 | 18.1 | 582 | 2.71 | 90.2 | 114 | .0117 | 1287 | 705 | .835 | --- | --- |
| | 10,400 | 21.0 | 617 | 3.06 | 83.0 | 168 | .0153 | 1493 | 876 | .808 | --- | --- |
| | 11,300 | 24.5 | 648 | 3.32 | 90.8 | 210 | .0176 | 1759 | 1111 | .912 | --- | --- |
| 50,000 | 10,400 | 12.8 | 611 | 1.65 | 81.5 | 156 | .0263 | 1725 | 1114 | .634 | --- | --- |
| | 11,300 | 14.9 | 655 | 1.81 | 82.3 | 194 | .0297 | 1989 | 1334 | .691 | --- | --- |
| 55,000 | 10,400 | 9.80 | 605 | 1.10 | 70.3 | Required temperature rise unattainable | | | | | | |
| | 11,300 | 11.8 | 641 | 1.26 | 70.8 | 171 | .0377 | 2140 | 1499 | .666 | --- | --- |
| 60,000 | 11,300 | 9.20 | 657 | .805 | 59.6 | Required temperature rise unattainable | | | | | | |

2428

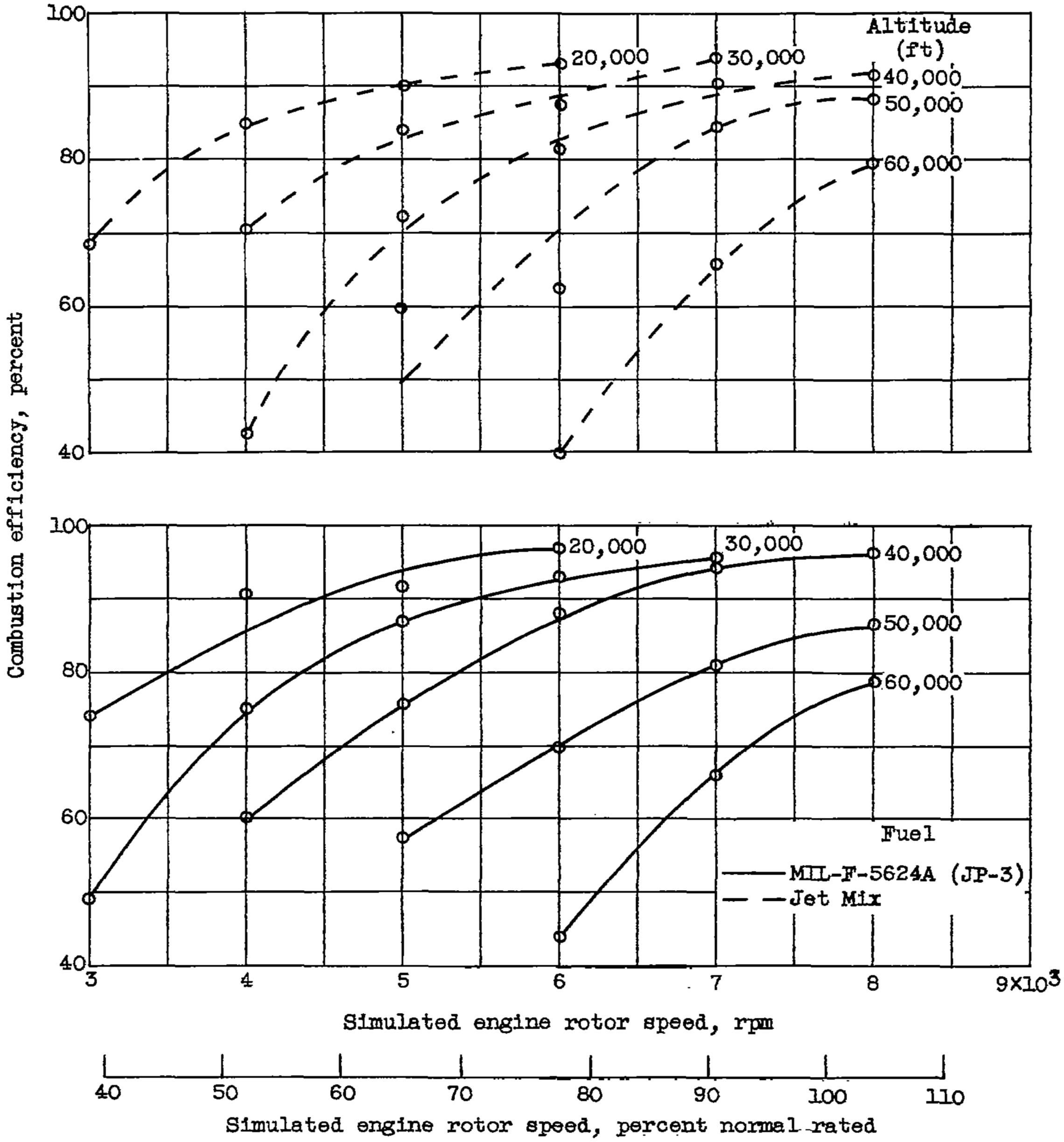



(a) J33 combustor.

Figure 1. - Variation of combustion efficiency with simulated engine rotor speed over altitude range from 20,000 to 60,000 feet for several combustors. Fuels, Jet Mix and MIL-F-5624A (JP-3); Mach number, 0.6.

[redacted]

2428

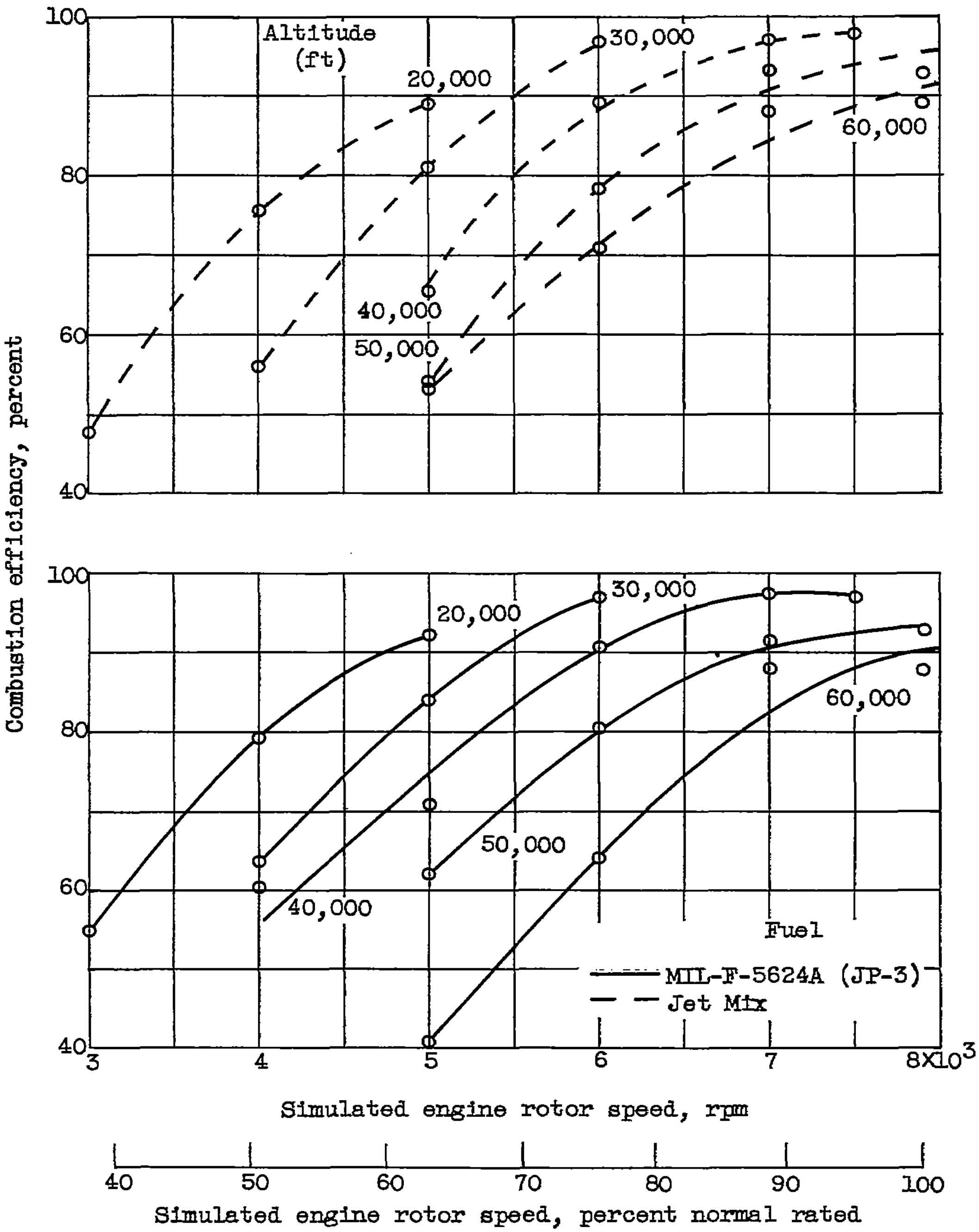



(b) J35 combustor.

Figure 1. - Continued. Variation of combustion efficiency with simulated engine rotor speed over altitude range from 20,000 to 60,000 feet for several combustors. Fuels, Jet Mix and MIL-F-5624A (JP-3); Mach number, 0.6.

[redacted]

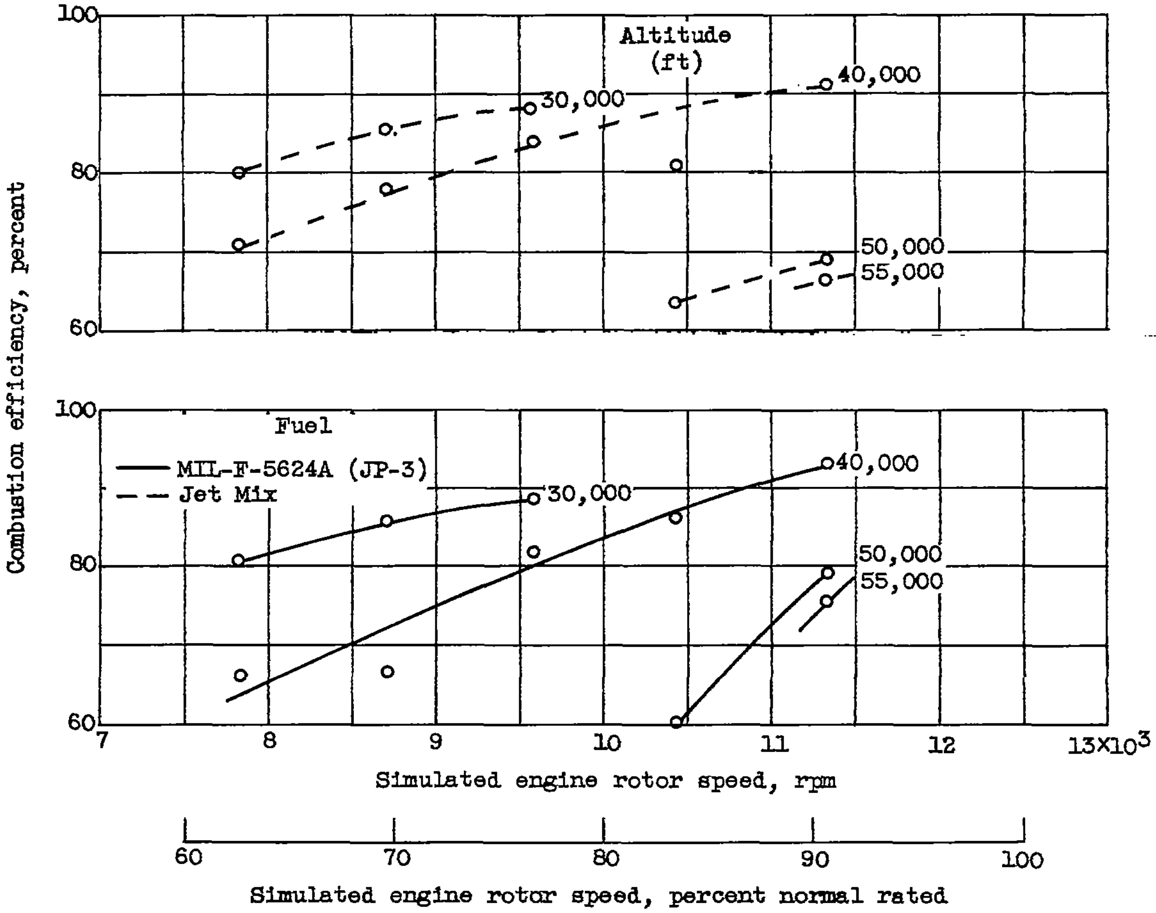
2428




(c) J47 combustor.

Figure 1. - Continued. Variation of combustion efficiency with simulated engine rotor speed over altitude range from 20,000 to 60,000 feet for several combustors. Fuels, Jet Mix and MIL-F-5624A (JP-3); Mach number, 0.6.

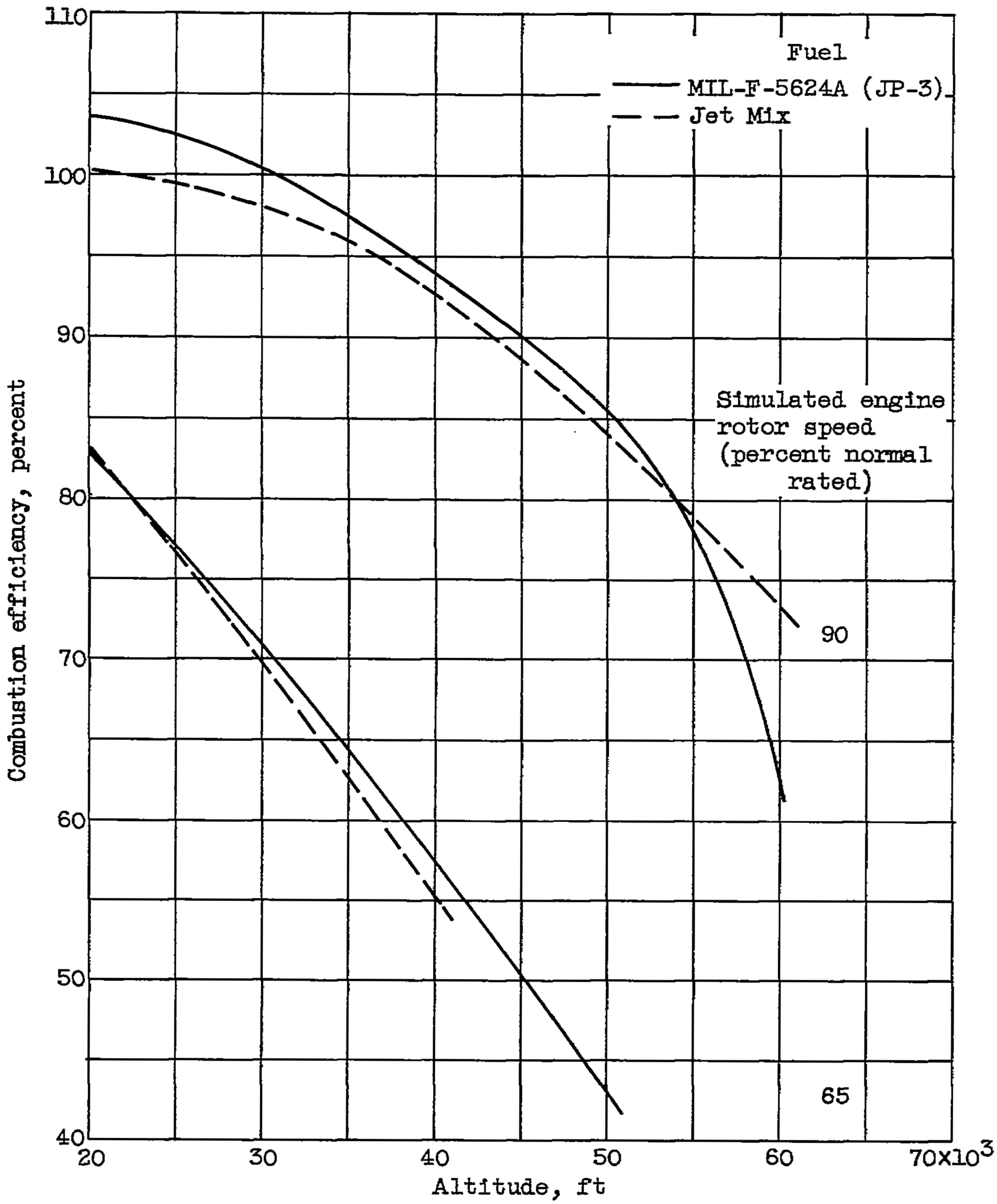
2428




(d) NACA annular combustor.

Figure 1. - Concluded. Variation of combustion efficiency with simulated engine rotor speed over altitude range from 20,000 to 60,000 feet for several combustors. Fuels, Jet Mix and MIL-F-5624A (JP-3); Mach number, 0.6.

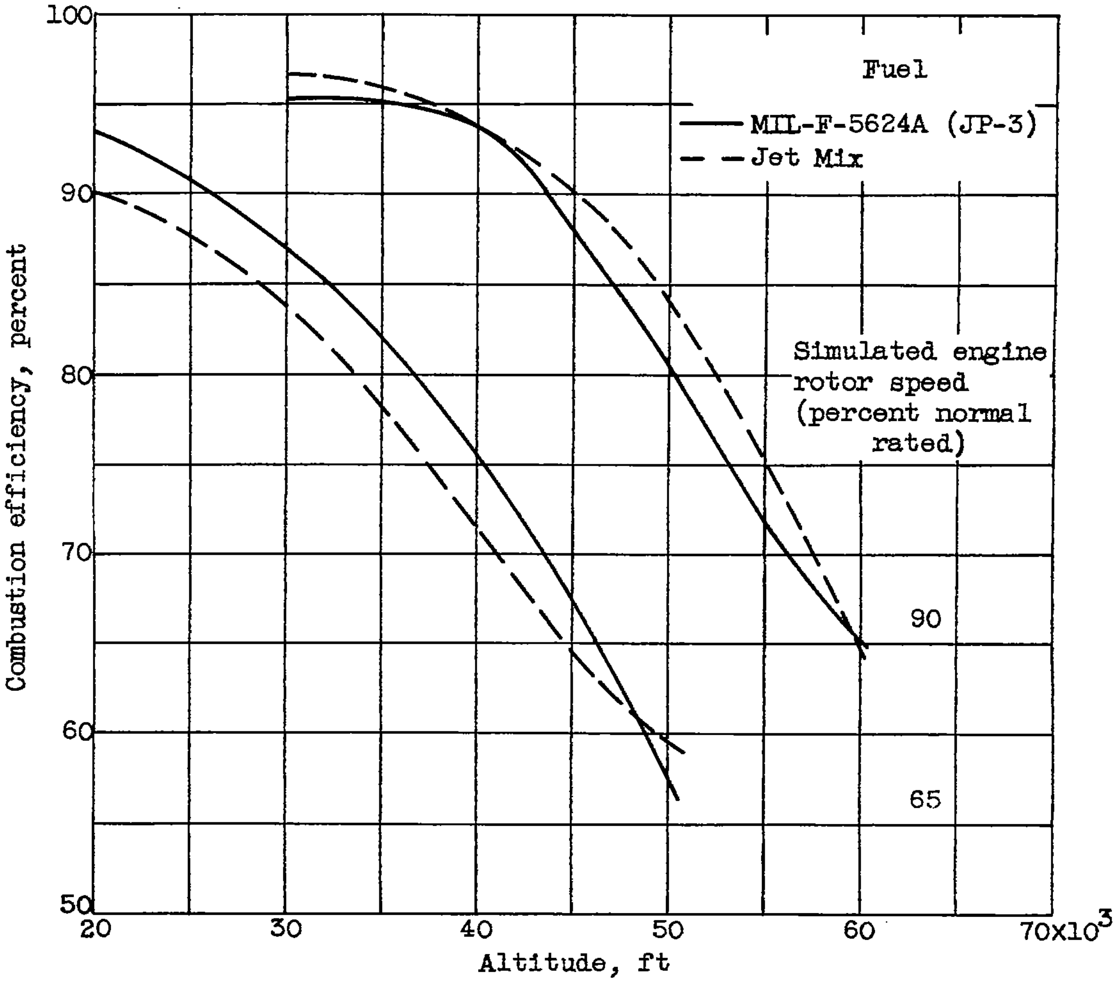
2428




(a) J33 combustor.

Figure 2. - Effect of altitude on combustion efficiency obtained at two constant simulated rotor speeds for several combustors. Fuels, Jet Mix and MIL-F-5624A (JP-3); Mach number, 0.6.

[redacted]

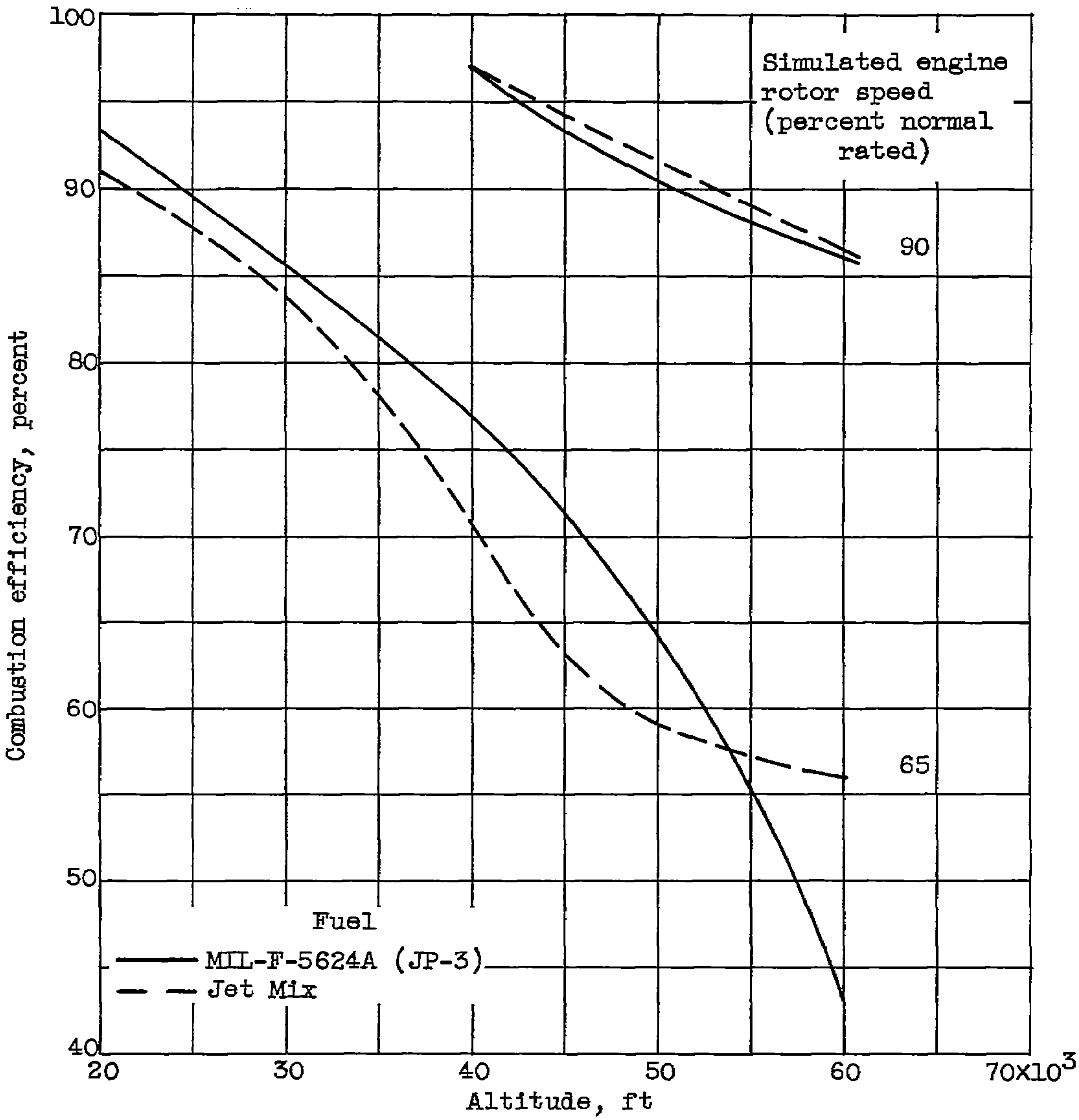



(b) J35 combustor.

Figure 2. - Continued. Effect of altitude on combustion efficiency obtained at two constant simulated rotor speeds for several combustors. Fuels, Jet Mix and MIL-F-5624A (JP-3); Mach number, 0.6.

2428

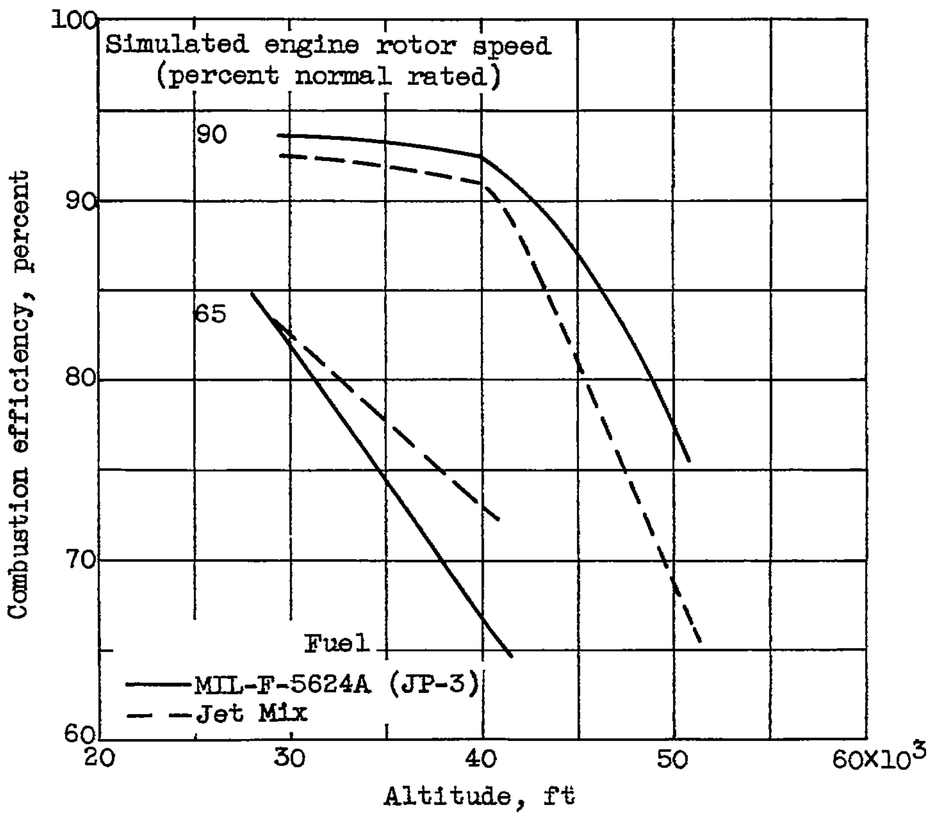
CP-3 back




(c) J47 combustor.

Figure 2. - Continued. Effect of altitude on combustion efficiency obtained at two constant simulated rotor speeds for several combustors. Fuels, Jet Mix and MIL-F-5624A (JP-3); Mach number, 0.6.

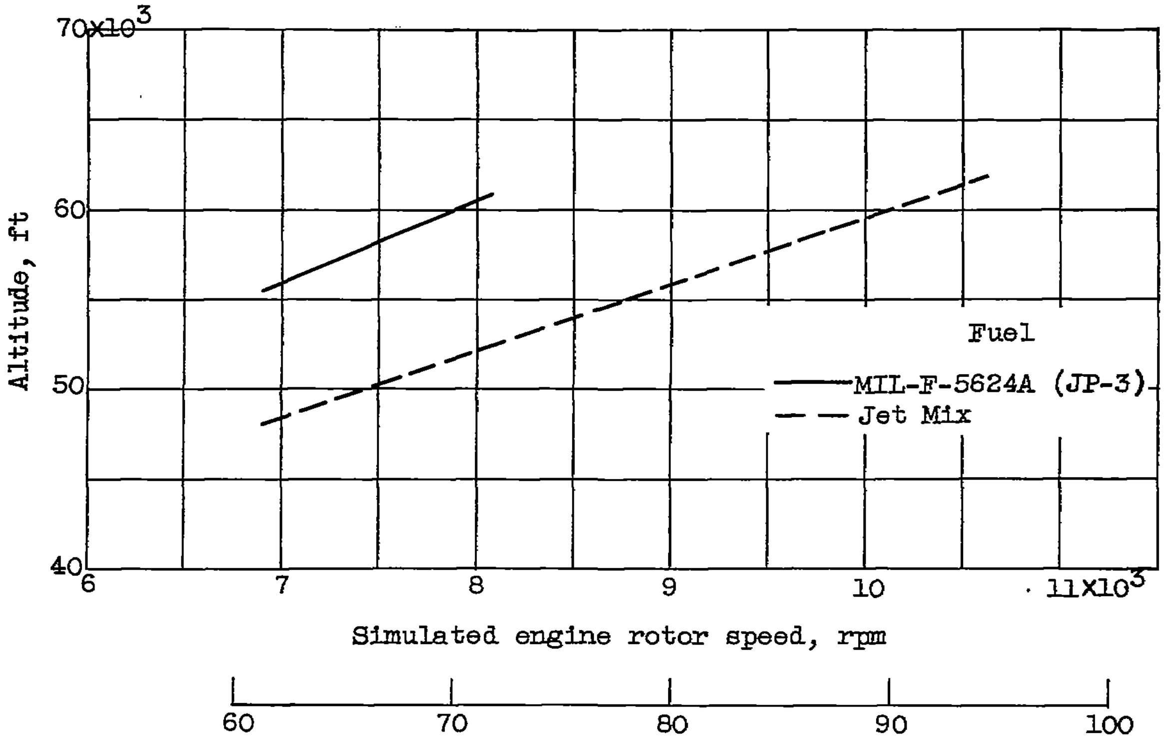
2428




(d) NACA annular combustor.

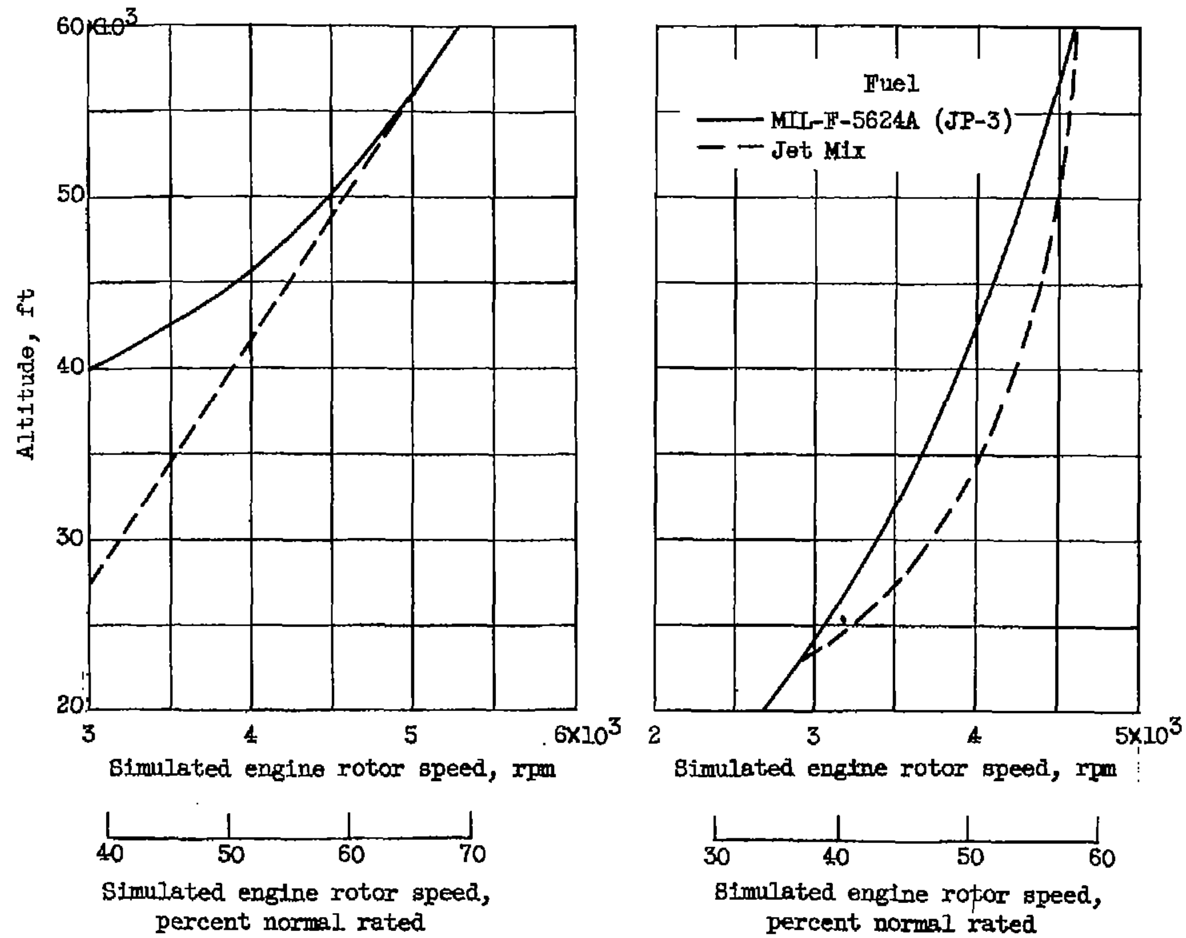
Figure 2. - Concluded. Effect of altitude on combustion efficiency obtained at two constant simulated rotor speeds for several combustors. Fuels, Jet Mix and MIL-F-5624A (JP-3); Mach number, 0.6.

2428




(a) J33 combustor.

Figure 3. - Comparison of altitude operational limits obtained with Jet Mix and MIL-F-5624A (JP-3) fuels for several combustors. Mach number, 0.6.

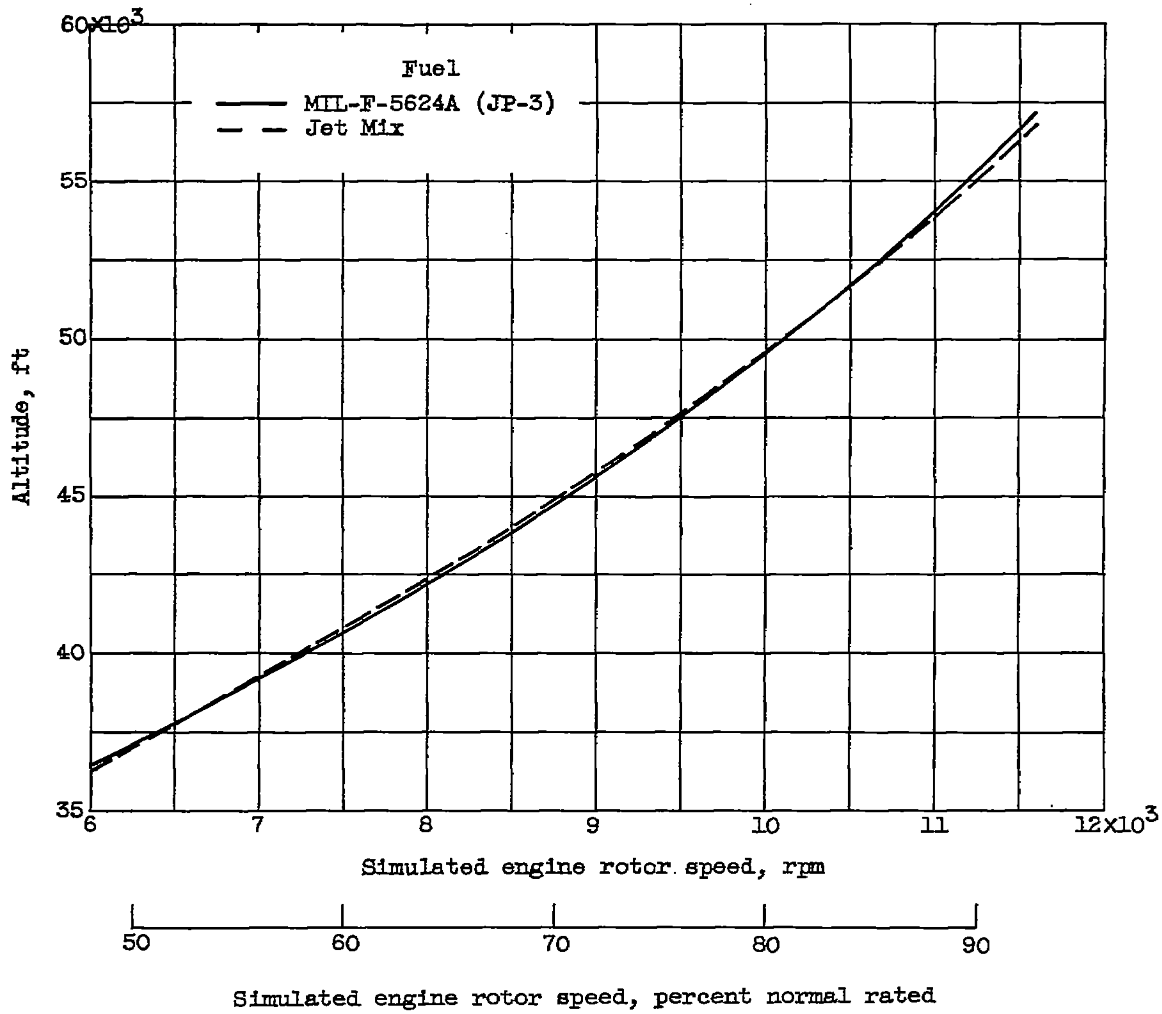



(b) J35 combustor.

(c) J47 combustor.

Figure 3. - Continued. Comparison of altitude operational limits obtained with Jet Mix and MIL-F-5624A (JP-3) fuels for several combustors. Mach number, 0.6.

2428




(d) NACA annular combustor.

Figure 3. - Concluded. Comparison of altitude operational limits obtained with Jet Mix and MIL-F-5624A (JP-3) fuels for several combustors. Mach number, 0.6.

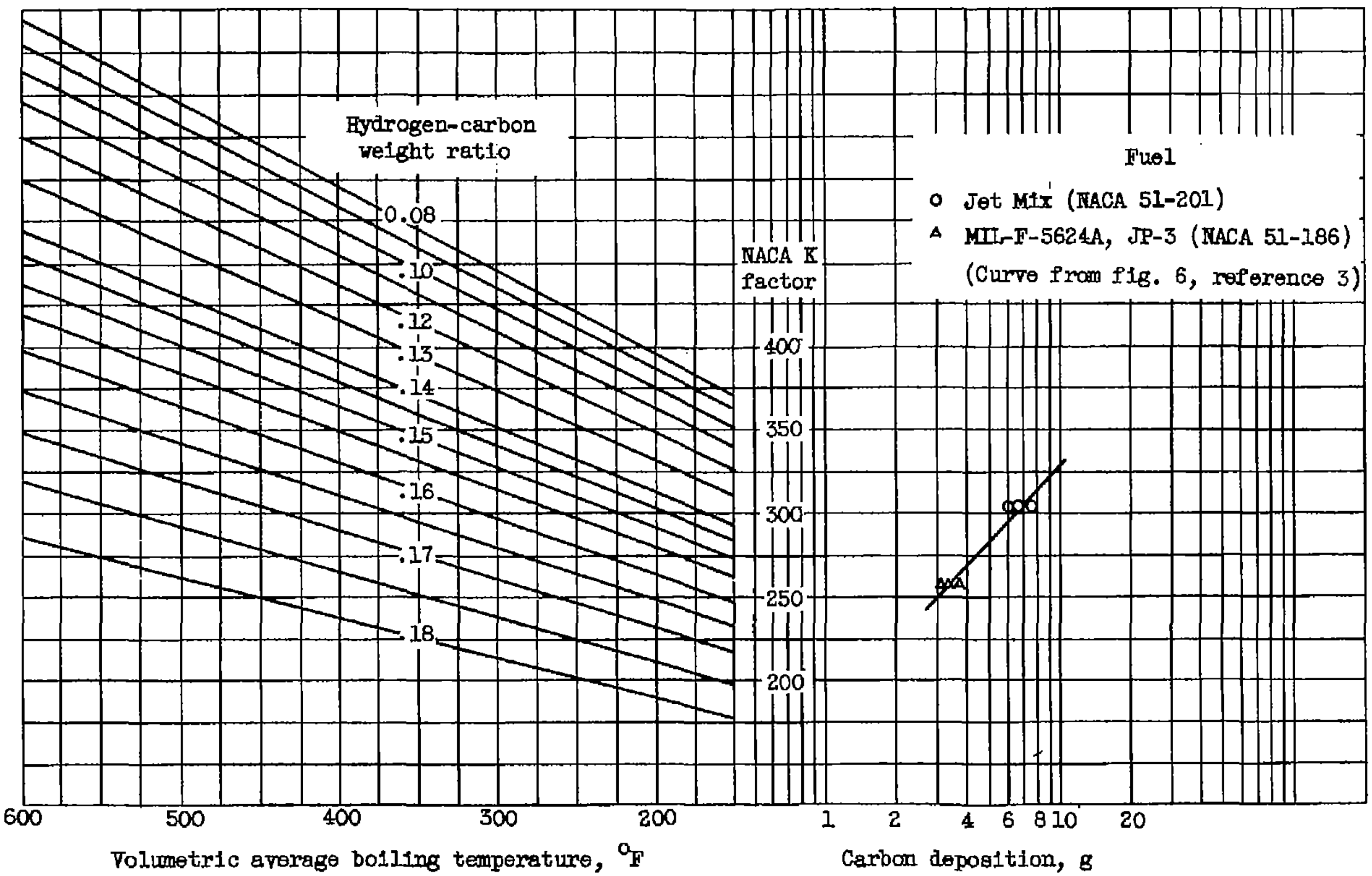



Figure 4. - Carbon deposition of Jet Mix and MIL-F-5624A (JP-3) fuels correlated with volumetric average boiling temperature and hydrogen-carbon weight ratio in J33 combustor. Simulated engine conditions: altitude, 20,000 feet; engine speed, 90-percent normal rated; Mach number, 0.0; run time, 4 hours.

[redacted]